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Storm Water Impacts on Creeks

Variability of Secondary Estuarine Watershed Creeks

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Abstract

The variability of water quality parameters (temperature, salinity, pH, and oxygen) was monitored in two estuarine creeks of the Charleston Harbor watershed. One watershed was a well-developed urbanized community with .3 to .5 acre housing lots, shopping centers, heavily trafficked roads, and storm drains routed into the estuary. The second site was a less well-developed forested watershed in the early stages of becoming an upstage low density housing community with 1 to 2 acre lots, golf course, and stormwater catchment system. In-situ monitoring at five minute intervals was used to assemble a composite record of annual variability. Both creeks show a strong seasonal variability driven by the annual solar cycle, a warming with the onset of spring and summer and a subsequent cooling in the fall. Oxygen and pH values are highly correlated, suggesting that a large portion of the oxygen dynamics of these creeks are controlled by biological metabolic processes. On occasion, both creeks recorded extremely low oxygen and high, above saturation, oxygen levels suggesting that a single regulatory standard for oxygen levels may be out of keeping with the dynamics of natural limits.

The summary statistics for each creek revealed no major differences between the creeks. However, analysis of the high frequency data suggests that these two creeks differ in their response to periods of intense rainfall; perturbations caused by rainfall seems to have a larger impact on creeks with urbanized watersheds. The urbanized creek displays a weaker high frequency periodic signal, perhaps due to channelization and increased sheet runoff. In the creek with a forested watershed the periodicity of the tides is conserved during rainfall as the water is intercepted by the land and released into the estuary through groundwater seepage.

Storm events trigger short term oxygen depletion in estuarine creeks by causing increases in the water column respiration rate. This increased biological oxygen demand appears to be due to anthropogenic changes in land use which diverge from the generally conservative character of natural systems. Such chronic stress may alter the natural selective forces on the creek community which may effect primary production, community structure and/or biodiversity. Such stress could be reduced by designing stormwater drainage systems for new and existing developments that better trap organic carbon and other materials and more closely mimic the path of runoff in natural systems.

Introduction

Estuaries are among the most productive of habitats, but also the most harsh, for resident organisms must adapt to continual changes that accompany the mixture of limnetic and oceanic waters. Estuaries are characterized by gradients and fluctuations in salinity, water temperature, and changes in concentrations of dissolved oxygen, particulate matter, and nutrients. Behind the biology of the estuarine system are numerous driving forces-- those of physical, chemical, and geological nature. Waters of different chemical composition (e.g. varying in chemical species and ionic strength) readily mix over a tidal cycle in a situation that is complicated by factors such as estuary topography, rainfall, sediment resuspension, and high levels of biological activity. Biogeochemical processes create not only noticeable gradients of components, but patchiness as well, depending on factors such as tidal velocity, mixing, flocculation, and uptake.

The principle input of fresh water in Charleston Harbor comes from the upland watershed of the Cooper River. The watersheds of the Ashley and Wando Rivers are in the Low Country and are fed principally through rain, groundwater seepage and runoff. The interface between these watersheds and the estuarine system are the salt marshes that border the land and are dissected by dendritic estuarine creeks.

Southeastern estuarine creeks are the primary nursery grounds for the larvae of most ecologically, commercially and recreationally important fish and crustacean species. Today, there is a growing body of evidence that the process of urbanization dramatically increases the transfer rate of terrestrial materials to coastal estuaries (Boyton et al., 1992). While there is an obvious pressing need to understand how anthropomorphic changes will interact with and change ecosystems in estuaries and coastal waters, insufficient information exists on the nature and importance of couplings between coastal watershed and estuaries. Because water is the vehicle of transport, the flow of beneficial and harmful materials is tightly coupled to the dynamics of the hydrologic cycle. Estuarine life, ranging from microscopic phytoplankton to large nekton, birds, and marine mammals, is therefore inexorably linked to rainfall in the watershed of the estuarine environment (Portnoy, 1991).

Coastal forests and other natural ecosystems play a buffering role in the conservation of ecosystem nutrients and particulates (Likens et al., 1985). Anthropogenic changes in land use such as deforestation, clearing, and agriculture disrupt the natural functioning of intricate biogeochemical cycles that tend to conserve nutrients and trap particulates in upland watersheds. Disturbance of these watersheds increases the export through the estuary in proportion to the magnitude of the perturbation. So while the transfer of terrestrial materials to the sea fuels the intense biological activity found in coastal estuaries (Day et al., 1989), human caused increases in nutrient loading may enhance primary production to the point of overload, which then leads to eutrophication. Accompanied increases in sediment loading tend to block the light required for phytoplankton production while additional dissolved and particulate carbon inputs enhance rates of microbial respiration contributing to further decreases in oxygen levels (Howarth et al., 1991). When taken *in toto*, the decline of "water quality" conditions can damage the ecological integrity of a system as evidenced by decreasing fisheries production and loss of biodiversity.

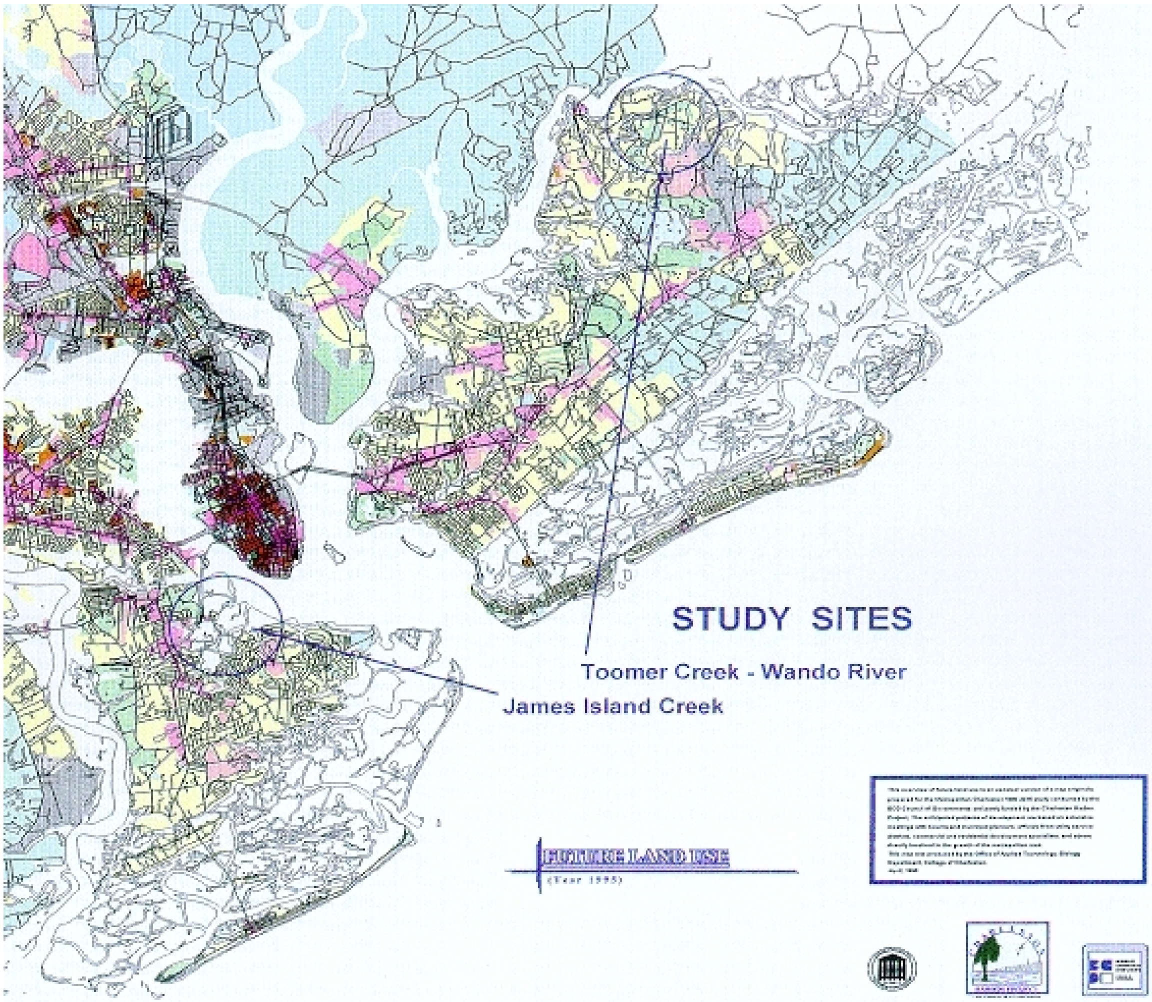
The hypothesis has its beginnings in the aftermath of Hurricane Hugo, when much of the watershed of Charleston was severely damaged. Most of the estuarine creeks became anoxic for weeks after the storm and fisheries surveys showed that larval fish year class in the estuarine creeks was virtually eliminated. Tropical Storm Klaus inundated Charleston with approximately eight inches of rain the following September which resulted again in severely depressed oxygen levels in estuarine waters.

In short, estuarine life, ranging from the microscopic plankton to fish, birds, and marine mammals inexorable linked to land use and rainfall in the watershed.

The focus of the work presented here is an attempt to characterize the natural temporal variability of water quality in two estuarine creeks, one with a watershed that is highly urbanized and the other possessing a forested watershed, to assess how watershed land use practices affect the ecology of the Charleston Harbor estuary. Hurricane Hugo, September 1989, severely damaged much of the watershed of the Charleston tri-county area. The estuarine creeks became anoxic for weeks after the storm and later surveys revealed that the year class of larval fish had been virtually eliminated. The following September, Tropical Storm Klaus inundated the region with approximately eight inches of rain which again severely depressed oxygen levels in estuarine waters (Abel et al, 1991; Dustan et al. 1991). Since these storms had dramatic effects on the ecology of estuarine creeks, I began to question the effects of long term chronic impact of land use on estuarine water quality which might possibly lead to chronic eutrophication and/or reduced habitat viability. The working hypothesis was that land use alters the coupling between coastal watershed and estuary through changes in the loading of dissolved and particulate materials. Small, but persistent increases over time might possibly change the character of estuarine creeks. Since there were virtually no data available on the high frequency variability of creeks it became necessary to sample creeks with both urbanized and forested watersheds. The forested watershed creek would be construed as the control creek so that deviations from natural patterns of variability might be detectable through time series analysis.

Study Sites

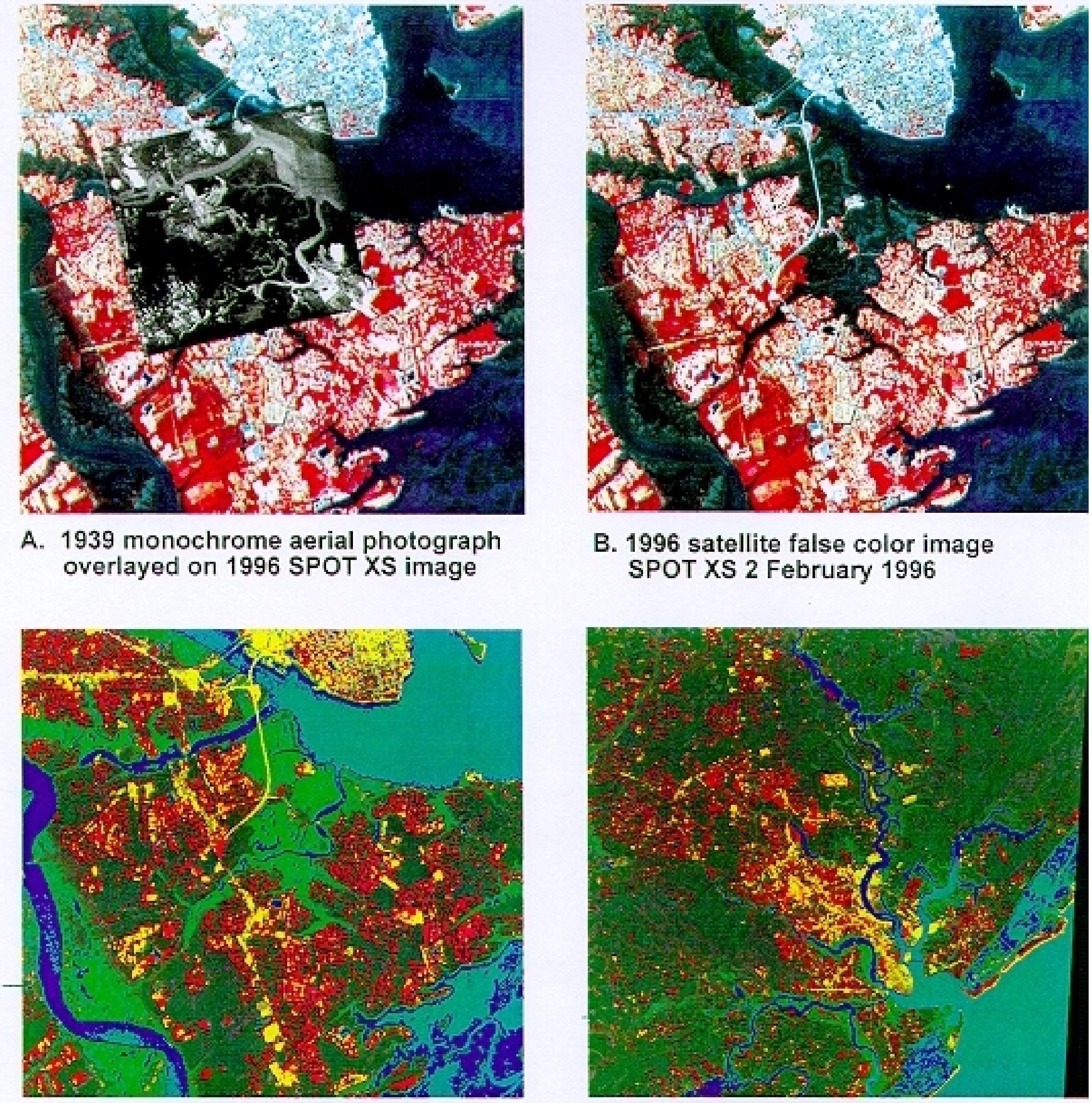
Sampling occurred in two tidal creeks in the Charleston Harbor estuary, James Island Creek and Toomer Creek (Fig. 1).



James Island Creek

James Island Creek (Fig. 2), bordered by dense salt marsh, is a small, tidally dominated tributary of Charleston Harbor, experiencing 1.6 m semidiurnal tides characteristic of the Charleston Area. Groundwater seepage is the only source of freshwater except heavy rainfall, so fresh water flow within the creek is small compared to tidal flow. The creek’s watershed was farmland in 1939 (Fig. 3) with large fields on the southern side of the estuary and a cluster of smaller farms to the west of Folly Road. The golf course of the Charleston Country Club was active and there was a road leading to Plum Island. Beginning in the 1960’s, the watershed slowly developed in to a medium density residential district. The mouth of James Island Creek is approximately 500 m downstream of the Plum Island wastewater treatment plant on the Ashley River. Highway runoff from Folly Road and the new James Island Expressway, which was under construction within the estuary during the sampling period, add to anthropogenic factors already influencing the creek's drainage area.

James Island Creek, Charleston, SC



A. 1939 monochrome aerial photograph overlayed on 1996 SPOT XS image

B. 1996 satellite false color image SPOT XS 2 February 1996

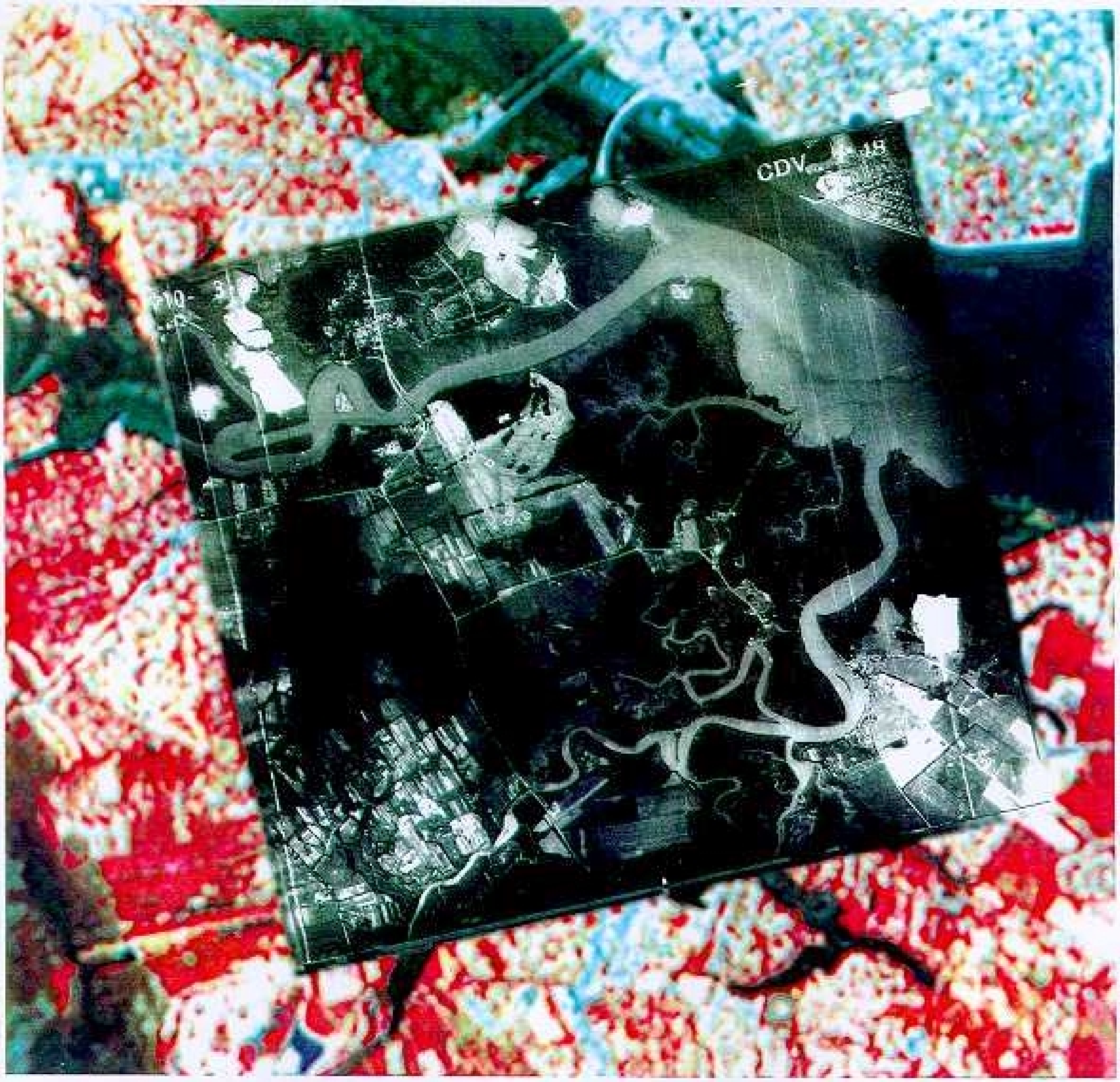
C. GIS classification of 1996 SPOT image

D. GIS classification of CHP Study Area

dense urban suburban forested

Figure 2.

James Island Creek, Charleston, SC



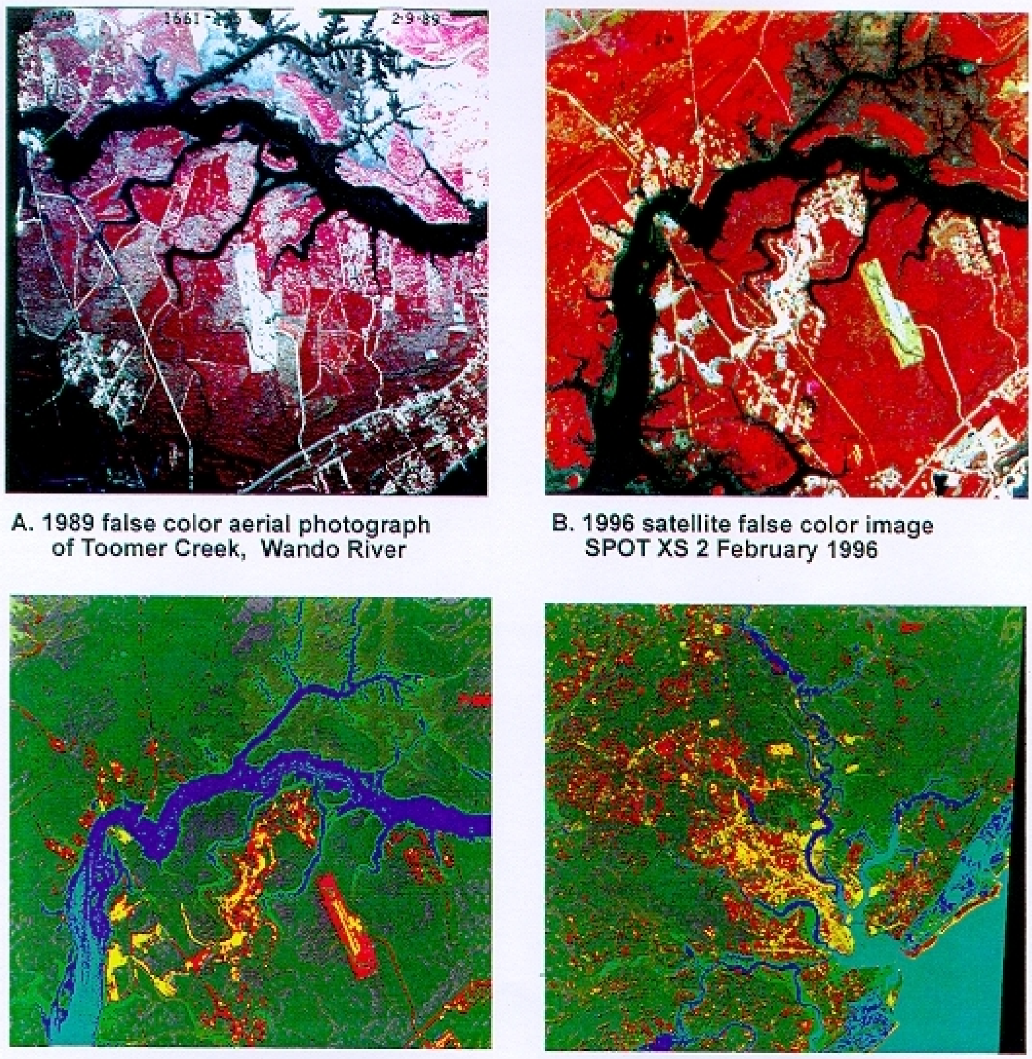
1939 Aerial photograph overlayed on 1996 SPOT image

Figure 3.

Toomer Creek, Dunes West

Toomer Creek (Fig.4), located in the upper reaches of the Wando River, was chosen for this project because it was one of the least disturbed forested creeks in the area that could be reached by both land and water. Additionally, it is a forested ecosystem which will be challenged ecologically in future years as its watershed becomes increasingly altered. An examination of available aerial photographs revealed that in 1989 the watershed was primarily forested and transected by only a few roads. By 1996, the property on the western shore of Toomer Creek showed signs of rapid development into an upscale residential community complete with an eighteen hole golf course. Much of the presently forested watershed of the Wando River in this region is slated to follow the path of Toomer Creek by the year 2010.

Toomer Creek, Wando River, Charleston SC



A. 1989 false color aerial photograph of Toomer Creek, Wando River

B. 1996 satellite false color image SPOT XS 2 February 1996

C. GIS classification of 1996 SPOT image

D. GIS classification of CHP Study Area

dense urban, suburban, forested

Figure 4.

Methods

Preliminary field investigations had shown that the estuarine creeks of Charleston Harbor exhibit almost no vertical stratification due to tidal mixing (Dustan et al. unpublished). For example, salinity rarely exceeds a 0.5 to 1 ppt difference between surface and bottom. As the tide floods in these creeks, friction with the sides and bottom causes tidal waves and currents which mix the water column (Pelegri , 1988, Blumberg and Goodrich, 1990, Sherwood et al., 1990, Simpson et al., 1990, Uncles and Stephens, 1990, Uncles and Stephens, l990b). Additionally, these creeks are relatively narrow, and while their maximum depths may approach 10 meters in a few areas, they are relatively shallow in relations to the fluctuation in tidal height which can be in excess of 1.8 meters. Thus, the overturn of the tides probably mixes these creeks from top-to-bottom during each tidal cycle. Bridges, boats and anything in the water can create turbulence and mix the water column (Kuo and Neilson, 1987; Schroeder et al., 1990). An additional study at James Island Creek to investigate vertical stratification during storm runoff conditions found that the water column in the creek does not become vertically stratified with respect to dissolved oxygen or salinity. Thus, under “normal” and storm conditions, a single point monitoring scheme at a strategic location could be employed to study the temporal of water quality variability within the estuarine basin.

Monitoring

Conventional sampling of water quality has been limited to irregular, widely spaced collections (monthly, etc.) which either show no trends, or are difficult to interpret. This project required continuous electronic monitoring to produce a high resolution time series data set of the natural variations which occur in this system. Sampling was carried out using self-contained, submersible, multiparameter probes (Hydrolab Datasonde^{TM} 3) to record *in-situ* temperature, salinity, pH, and dissolved oxygen continuously at five minute intervals. The instruments were deployed from floating docks at a fixed depth of approximately 1 meter beneath the surface. They were serviced and downloaded at three to four day intervals as longer periods resulted in fouling of the oxygen membranes (Lo-Flo, HydroLab Corp.).

Instruments were deployed in both creeks during 1992-3, and again in James Island Creek during 1994 and 1995. During the summer of 1995, two and sometimes three instruments were deployed simultaneously in James Island Creek to check instrument variability. Temperature, salinity and pH calibrations were very consistent and usually within the advertised instrument error of a tenth of a unit. Readings of oxygen concentration were not as stable which necessitated careful calibration, and diligent electrode maintenance before and after every deployment,

The data were downloaded and the files concatenated into data files of a month in length. These data were summarized into weekly means to visualize annual trends. Selected time periods were used to illustrate aspects of the variability of the data and the response of each system to storms. Data analysis and statistical plotting were accomplished using Statistica^{TM} 4.0 (Stat Soft Inc., 1994). Spectral analysis (fast fourier transformations) was performed on selected periods of continuous data (5 minute periodicity) using the algorithms in Statistica$^{TM.}$. Frequency was converted to wavelength in hours and plotted with x-y plots of spectral density vs. wavelength.

Dissolved Nutrients

Discrete samples were taken over several tidal cycles. Samples were collected in duplicate or triplicate in acid washed containers, filtered (GFF) and analyzed for dissolved plant nutrients (NO_2, NO_3, NO_4, PO_4, SiO_4). Nutrient concentrations were determined on triplicate samples using a colorimetric analysis (Hach DR2000, pillow pack and AccuVac reagent systems).

Water Column Respiration

In-vivo bottle incubations were used to estimate biological oxygen demand. Water bottles (approx. 250 ml) were taken at low tide, wrapped in aluminum foil and incubated underwater for as long as seventy two hours as preliminary studies had shown this to be more than sufficient to estimate the respiratory rate of the sample. Oxygen concentrations were determined on triplicate samples using a colorimetric analysis (Hach DR2000, AccuVac system) based on the Winkler method.

Image Analysis

Sets of images were assembled for each watershed area from available aerial photography and satellite imagery. Photographs were digitized using and Eikonix RGB digital camera system. Image processing and GIS analysis were accomplished using ERDAS^{TM} and Imagine^{TM} software.

Tides

Tidal information was obtained through Tide1: Rise & Fall^{TM} software from Micronautics, Inc.

Results

Time Series

Data records from each creek consist of a near continuous record for approximately one year. Data taken from Toomer Creek is nearly continuous from January 1993 to December 1993, excluding the months of July and August. Data from James Island Creek represents sampling from December 1992 through May 1993, and June to November 1995. The data we have collected to date are voluminous comprising time series records 88,229 long for James Island Creek and 66,961 long for Toomer Creek. These data were summarized by taking the weekly mean for each variable (Appendix 1.).

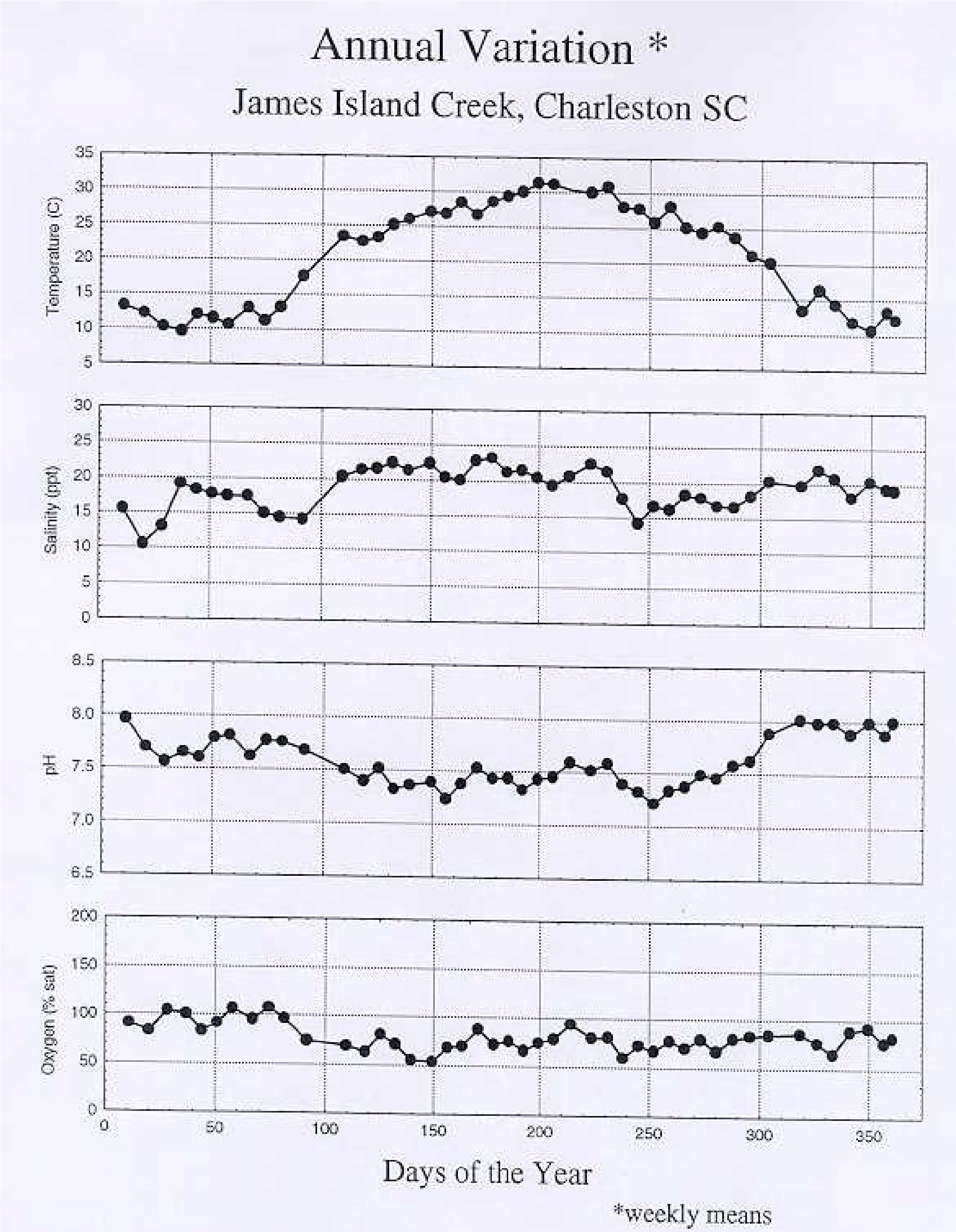

Annual Variation *
James Island Creek, Charleston SC
Temperature (C)
Salinity (ppt)
pH
Oxygen (% sat)
Days of the Year
*weekly means

Figure 5.

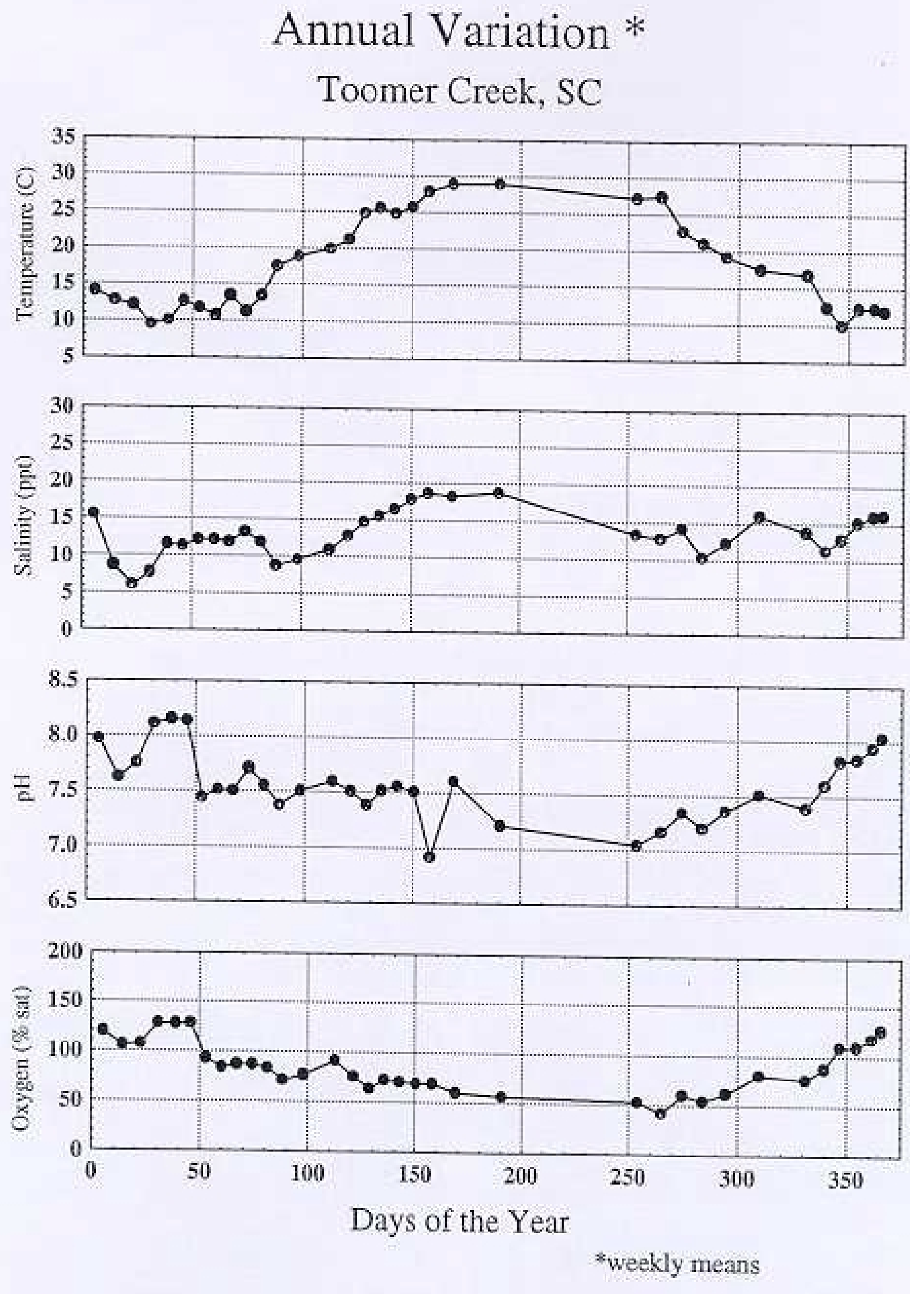


Figure 6.

Annual Variability

There are no striking differences in the descriptive statistics of the two creeks over the annual cycle (Fig. 5 and 6). Both creeks show a strong seasonal variability driven by the annual solar cycle. Both creeks show a warming with the onset of spring and summer and a subsequent cooling in the fall. Toomer Creek experienced slightly lower average temperatures (18 vs. 21.3 °C) and James Island Creek experiences a slightly warmer maximum temperature (33.6°C). Salinity tends to be highest in the spring and early summer months when rainfall is low and solar input high. Toomer Creek had a lower mean salinity (13.2 vs. 19 ppt) and a recorded zero salinity while James Island Creek dipped to 1.8 ppt (Table 1).

Table 1. Summary of water quality parameters for James Island Creek (JIC) and Toomer Creek (TC). The number of samples (n) varies due to data drop outs and missing data.

	Valid N		Mean		Minimum		Maximum		Std. Dev.	
Variable	**JIC**	**TC**	**JIC**	**TC**	**JIC**	**TC**	**JIC**	**TC**	**JIC**	**TC**
Temp. (°C)	88717	66979	21.28	18.01	7.02	4.19	33.63	31.79	7.51	6.54
pH	88718	66979	7.59	7.56	4.73	5.22	8.39	9.98	0.32	0.38
Salinity	88229	66979	18.97	13.16	1.80	0.00	27.20	20.20	3.58	3.66
Oxygen	88718	66961	79.60	84.61	4.10	0.00	200.00	194.60	21.52	25.73

Oxygen and pH in Toomer track the seasonal cycle, though not as faithfully as temperature and salinity. Recordings of pH and oxygen (percent saturation) suggest that respiration is higher in summer as temperatures increase. The mean pH of the two creeks is the same (7.6) but Toomer experienced a higher pH (9.98 vs. 8.4) and James Island Creek the lower pH (4.73 vs. 5.2). Toomer Creek experienced a higher oxygen concentration (84.6 vs. 79.6 percent saturation). On occasion, both creeks recorded extremely low oxygen and high, above saturation, oxygen levels. Toomer Creek displayed very high oxygen concentration levels in early February, while the signal was not nearly as strong in James Island Creek. Periods of extremely low oxygen levels were usually recorded in the early morning hours (pre-dawn) on low tides and seldom lasted more than a few sampling cycles (10 to 30 minutes).

The February oxygen increase in Toomer Creek is accompanied by a higher pH. This is suggestive of increased productivity. Unfortunately no data were collected to distinguish between increased benthic or phytoplankton production at the time. At James Island Creek, oxygen and pH values do not suggest a late February bloom, and in general are more variable throughout the year than at Toomer Creek. The absence of a February “bloom” in James Island Creek clearly merits further study for critical evaluation of the differences between estuarine creeks with urban and forested watersheds.

Tidal variation:

Oxygen levels strong linkage with tidal phase with oxygen levels higher at high tide. While the correlation between oxygen and salinity for each whole data set is low (0.08 and -0.17 respectively) there is a strong phase linkage between tidal stage and oxygen concentration with the highest levels of oxygen occurring on the high tide (Fig. 7). This pattern of high oxygen levels during high tide, was repeatedly observed except during periods of drought when the salinity signal was greatly dampened.